

4 DEVELOP A SURVEY DESIGN

4.1 Introduction

Once a decision rule has been developed, a disposition survey can be designed for the impacted materials and equipment (M&E) being investigated. The disposition survey incorporates all of the available information to determine the quantity and quality of data required to support a disposition decision. This chapter provides information on selecting the type, number, and location of measurements required to support a decision regarding the disposition of the M&E. Facilities or installations can use the process in this chapter and following chapters to develop a standard operating procedure (SOP) so multiple surveys can be performed for similar M&E to avoid costly and time-consuming development of redundant survey designs. The evaluation of existing SOPs for usability is discussed in Section 3.10. The output from this chapter is a documented disposition survey design that integrates measurement, data collection, and data analysis techniques.

The information in this chapter builds on the information collected and decisions made in Chapters 2 and 3. The disposition option selected in Section 2.5 and the action levels (ALs) identified in Section 3.3 are incorporated into the decision rules developed in Section 3.7. A decision rule is the basis for the disposition survey design. If multiple survey designs address the same decision rule and meet the data quality objectives (DQOs), the decision-maker needs to determine the most effective design for that decision rule. If none of the survey designs meet the DQOs for a specific decision rule, it may be necessary to reconsider decisions made earlier in the survey design process and adjust the DQOs.¹ If there are multiple decision rules (e.g., one for total radioactivity and one for removable radioactivity) more than one survey design may need to be developed to meet all of the DQOs for the project or a single survey design may be developed to incorporate all of the decision rules.

The complexity of a survey design generally reflects the complexity of the statistics used to interpret the results (Chapter 6). Survey designs range from simple (e.g., scan 100% of the M&E for surface radioactivity at a specified AL) to complex (e.g., develop a MARSSIM-type survey design). Simple survey designs typically require few resources for planning, but may require significant resources to implement. Complex survey designs typically require more resources during planning, with fewer resources required during implementation. If the planning and implementation portions of the data life cycle are performed correctly, the assessment and decision making stages should require few resources. This chapter provides information on statistical decision-making and how it is used during development of survey designs.

4.2 Making Decisions Using Statistics

In Section 3.6, the planning team assumed the levels and distribution of radioactivity associated with the M&E were known with no uncertainty. A theoretical decision rule was developed using this assumption to help focus the attention of the planning team on *how* they would make

¹ Refer to Section 2.3 for information on performing preliminary surveys to help ensure at least one survey design will meet the DQOs.

decisions. In this chapter the planning team accounts for uncertainty in decisions when ideal data are not available by establishing a statistical test to implement the decision rule. Decisions regarding the disposition of M&E are based on data with uncertainties. Through the use of statistics, the disposition survey design attempts to control the probability of making a decision error because of these uncertainties. MARSSIM Section 2.3 provides additional discussions on the use of statistics for making decisions based on environmental data. These steps are discussed briefly below and in further detail in Section 7.1. MARSAME recommends the planning team complete the following steps:

- Select a null hypothesis (Section 4.2.1),
- Choose a discrimination limit (Section 4.2.2),
- Define Type I and Type II decision errors (Section 4.2.5),
- Set a tolerable Type I decision error rate at the action level (Section 4.2.5), and
- Set a tolerable Type II decision error rate at the discrimination limit (Section 4.2.5).

4.2.1 Null Hypothesis

In hypothesis testing, two assertions about the actual level of radioactivity associated with the M&E are formulated. The two assertions are called the null hypothesis (H_0) and the alternative hypothesis (H_1). H_0 and H_1 together describe all possible radionuclide concentrations or levels of radioactivity under consideration. The survey data are evaluated to choose which hypothesis to reject or not reject, and by implication which to accept.² In any given situation, one and only one of the hypotheses must be true. The null hypothesis is assumed to be true within the established tolerance for making decision errors (Section 4.2.5). Thus, the choice of the null hypothesis also determines the burden of proof for the test.

4.2.2 Discrimination Limit

Action levels were defined in Section 3.3 based on the selected disposition option and applicable regulatory requirements. The planning team also chooses another radionuclide concentration or level of radioactivity that can be reliably distinguished from the action level by performing measurements (i.e., direct measurements, scans, in situ measurements, samples and laboratory analyses). This radionuclide concentration or level of radioactivity is called the discrimination limit (DL). An example where the discrimination limit is defined is provided in Section 8.4.5. The gray region is defined as the interval between the action level and the discrimination limit (Figures 4.1, 4.2, and 4.3 provide visual descriptions of the gray region). The width of the gray region is called the shift and denoted as Δ . The objective of the disposition survey is to decide whether the concentration of radioactivity is more characteristic of the DL or of the AL, i.e., whether action should be taken, or if action is not necessary. The width of the gray region expressed as a multiple of the measurement standard deviation, σ , is called the relative shift, $\tilde{\Delta}\sigma$. Survey effort will increase as the relative shift decreases.

² In hypothesis testing, to “accept” the null hypothesis only means not to reject it. For this reason many statisticians avoid the word “accept.” A decision not to reject the null hypothesis does not imply the null hypothesis has been shown to be true.

In Figure 4.1, it may be seen that a large σ can be tolerated because Δ is large enough that the resulting relative shift Δ/σ is large. In Figure 4.2, even though σ is small, either more accuracy or more samples are needed because Δ/σ is also small.

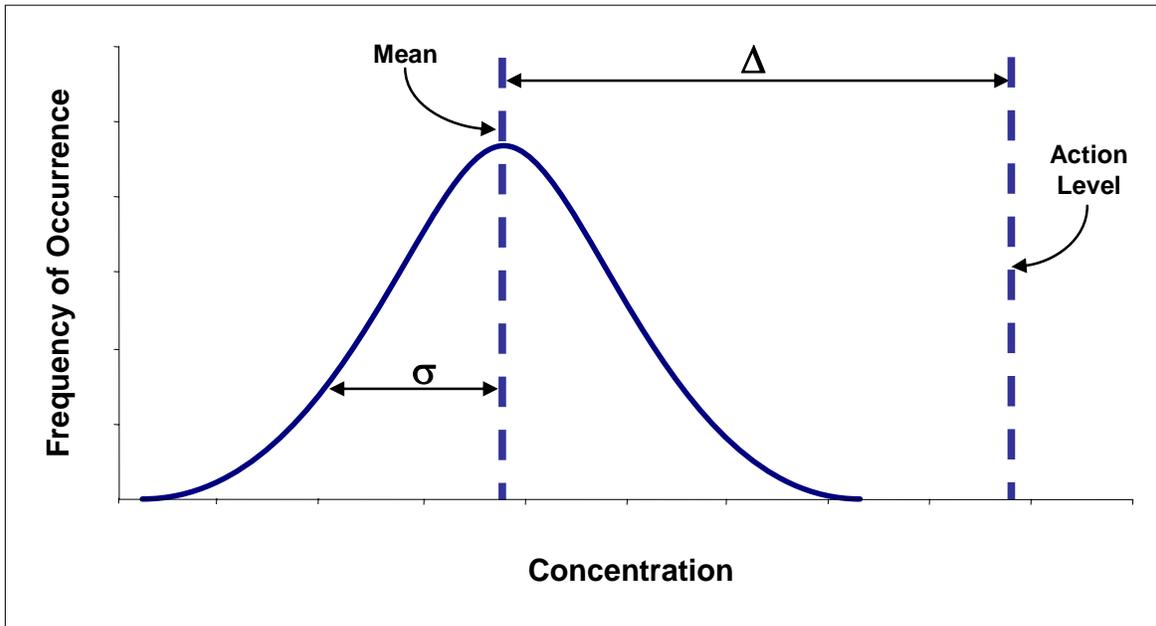


Figure 4.1 Relative Shift, Δ/σ , Comparison for Scenario A: σ is Large, but the Large Δ Results in a Large Δ/σ and Fewer Samples

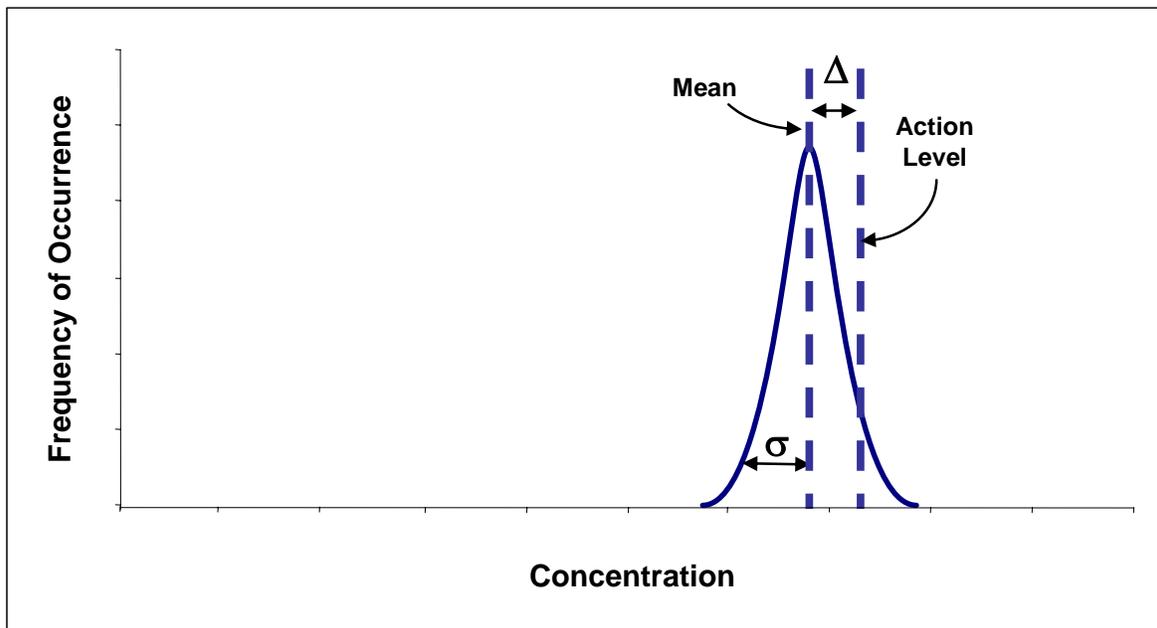


Figure 4.2 Relative Shift, Δ/σ , Comparison for Scenario A: σ is Small, but the Small Δ Results in a Small Δ/σ and More Samples

4.2.3 Scenario A

The null hypothesis for Scenario A specifies that the radionuclide concentration or level of radioactivity associated with the M&E is equal to or exceeds the action level. For Scenario A ($H_0: X > AL$), the upper bound of the gray region (UBGR) is equal to the AL and the lower bound of the gray region (LBGR) is equal to the DL. As a general rule for applying Scenario A, the DL should be set no higher than the expected radionuclide concentration associated with the M&E. The DL and the AL should be reported in the same units. Figure 4.3 illustrates Scenario A.

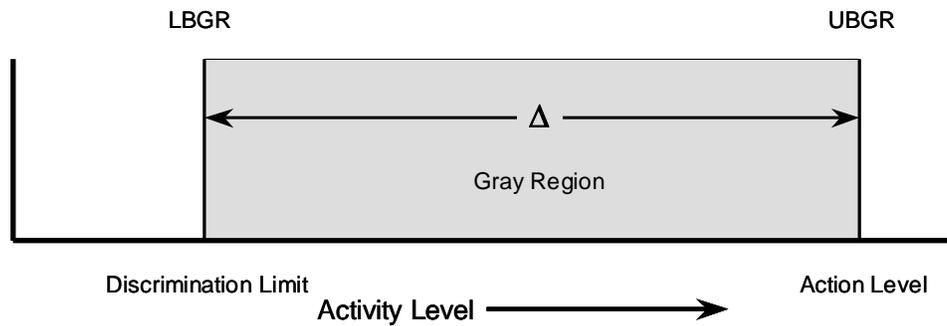


Figure 4.3 Illustration of Scenario A

4.2.4 Scenario B

The null hypothesis for Scenario B specifies the radionuclide concentration or level of radioactivity associated with the M&E is less than or equal to the action level. For Scenario B ($H_0: X \leq AL$), the UBGR is equal to the DL and the LBGR is equal to the AL. The DL defines how hard the surveyor needs to look, and is determined through negotiations with the regulator.³ In some cases the DL will be set equal to a regulatory limit (e.g., 10 CFR 36.57 and DOE 1993).

The DL and the AL should be reported in the same units. Figure 4.4 illustrates Scenario B. This description of Scenario B is based on information in MARLAP and is fundamentally different from the description of Scenario B in NUREG-1505 (NRC 1998a).

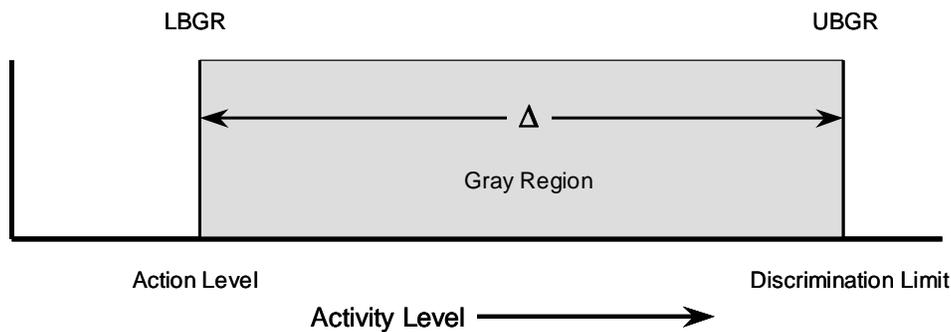


Figure 4.4 Illustration of Scenario B

³ In some cases, setting the discrimination limit may include negotiations with stakeholders.

In NUREG-1505 (NRC 1998a) the gray region is defined to be below the AL in both Scenario A and Scenario B. In MARSAME and MARLAP the gray region is defined to be above the AL in Scenario B. The difference lies in how the action level is defined.

4.2.5 Specify Limits on Decision Errors

There are two possible types of decision errors:

- Type I error: rejecting the null hypothesis when it is true, and
- Type II error: failing to reject the null hypothesis when it is false.

Because there is always uncertainty associated with the survey results, the possibility of decision errors cannot be eliminated. So instead, the planning team specifies the maximum Type I decision error rate (α) that is allowable when the radionuclide concentration or level of radioactivity is at or above the action level. This maximum usually occurs when the true radionuclide concentration or level of radioactivity is exactly equal to the action level. The planning team also specifies the maximum Type II decision error rate (β) that is allowable when the radionuclide concentration or level of radioactivity equals the discrimination limit. Equivalently, the planning team can set the “power” ($1-\beta$) when the radionuclide concentration or level of radioactivity equals the discrimination limit. See MARSSIM Appendix D, Section D.6 for a more detailed description of error rates and statistical power.

It is important to clearly define the scenario (i.e., A or B) and the decision errors for the survey being designed. Once the decision errors have been defined, the planning team should determine the consequences of making each type of decision error. For example, incorrectly deciding the activity is less than the action level may result in increased health and ecological risks. Incorrectly deciding the activity is above the action level when it is actually below may result in increased economic and social risks. The consequences of making decision errors are project specific.

4.2.6 Develop an Operational Decision Rule

The theoretical decision rule developed in Section 3.6 was based on the assumption that the true radionuclide concentrations in the M&E were known. Because the disposition decision will be made based on measurement results and not the true but unknown concentration, an operational decision rule needs to be developed to replace this theoretical decision rule. The operational decision rule is a statement of the statistical hypothesis test, which is based on comparing some function of the measurement results to some critical value. The theoretical decision rule is developed during Step 5 of the DQO process (Chapter 3), while the operational decision rule is developed as part of Step 6 and Step 7 of the DQO process. For example, a theoretical decision rule might be “if the results of any measurement identify surface radioactivity in excess of background, the front loader will be refused access to the site; if no surface radioactivity in excess of background is detected, the front loader will be granted access to the site.” The related operational decision rule might be “any result that exceeds the critical value associated with the MDC set at the discrimination limit will result in rejection of the null hypothesis, and the front loader will not be allowed on the site” (see more examples in Chapter 7).

4.3 Classify the Materials and Equipment

Classification is used to determine the level of survey effort for the disposition survey. The level of survey effort is linked to the potential to exceed the action level(s) (i.e., classification), and is a graded approach to survey design. Impacted M&E with the highest potential to exceed the action level(s) (i.e., Class 1) receive the greatest effort for the disposition survey, while M&E with a lower potential to exceed the action level(s) (i.e., Class 2 or Class 3) require less survey effort. Classification in MARSAME is analogous to classification in MARSSIM. The planning team needs to remember that classification is based on estimated radionuclide concentrations or radioactivity relative to the AL.

There are tradeoffs (costs and benefits) associated with classification based on estimated⁴ or known radionuclide concentrations or levels of radioactivity relative to the action levels. This means that some knowledge of radionuclide concentrations is required before M&E can be classified. Known radionuclide concentrations or levels of radioactivity may be available from historical data identified during the initial assessment (IA; see Section 2.2), or performance of preliminary surveys (Section 2.3). Estimates of radionuclide concentrations can be developed based on historical data or process knowledge (Section 2.2). In the absence of information on the radionuclide concentrations, the default assumption is that all impacted M&E are Class 1.

Because classification of impacted M&E is based in part on an action level, classification cannot be performed until potential action levels have been identified (Section 3.3). For projects where multiple potential action levels have been identified, classification and selection of an appropriate action level may be an iterative process used to reduce the number of survey options. Alternatively, multiple survey designs can be developed to address all potential action levels. In the final step of the DQO process the most resource efficient survey design that meets the survey objectives is selected (Section 4.4.4).

4.3.1 Class 1

Class 1 M&E are impacted M&E that have, or had, the following: (1) highest potential for, or known, radionuclide concentration(s) or radioactivity about the action level(s); (2) highest potential for small areas of elevated radionuclide concentration(s) or radioactivity; and (3) insufficient evidence to support reclassification as Class 2 M&E or Class 3 M&E. Such potential may be based on historical information and process knowledge, while known radionuclide concentration(s) or radioactivity may be based on preliminary surveys. This class of M&E might consist of processing equipment, components, or bulk materials that may have been affected by a liquid or airborne release, including, for example, inadvertent effects from spills.

Class 1 M&E are those that may have been in direct contact with radioactive materials during operations or may have become activated and are likely to exceed the action level. Additionally, M&E that have been cleaned to remove residual radioactivity above the action level generally are considered to be Class 1. An exception to Class 1 classification may be considered if there

⁴ There are risks and tradeoffs associated with using estimated values. The planning team should compare the consequences of potential decision errors with the resources required to improve the quality of existing data to determine the appropriate approach for a specific project.

are no difficult-to-measure areas and any residual radioactivity is readily removable using cleaning techniques. Examples of such methods may include vacuuming, wipe downs, or chemical etching that quantitatively remove sufficient amounts of radionuclides such that surficial activity levels would be less than the release criteria. Documented process knowledge of cleaning methods directly applicable to the particular M&E should be provided to justify this exception.

4.3.2 Class 2

Class 2 M&E are impacted M&E that have, or had, (1) low potential for radionuclide concentration(s) or radioactivity above the action level(s); and (2) little or no potential for small areas of elevated radionuclide concentration(s) or radioactivity. Such potential may be based on historical information, process knowledge, or preliminary surveys. This class of materials might consist of electrical panels, water pipe, conduit, ventilation ductwork, structural steel, and other materials that might have come in contact with radioactive materials. Radionuclide concentration(s) and radioactivity above the action level, including small areas of elevated radionuclide concentration(s) or radioactivity, are not expected in Class 2 M&E.

4.3.3 Class 3

Class 3 M&E are impacted M&E that have, or had, (1) little, or no, potential for radionuclide concentration(s) or radioactivity above background; and (2) insufficient evidence to support categorization as non-impacted. Radionuclide concentration(s) and radioactivity above a specified small fraction of the UBGR are not expected in Class 3 M&E. The specified fraction should be developed by the planning team using a graded approach and approved by the regulatory authority.

4.3.4 Other Classification Considerations

The planning team should review any historical data used to provide information on radionuclide concentrations or radioactivity and evaluate whether or not the data meet the objectives of the disposition survey, as illustrated in the following examples. Representativeness (see MARSSIM Appendix N) is a key data quality indicator when evaluating historical data. Ideally, the IA should provide information on the radionuclides of potential concern, expected radionuclide concentrations or radioactivity, distribution of radioactivity, and locations where radioactivity is expected (e.g., surficial or volumetric, see Section 2.4.3). In addition, the data should meet the criteria for measurability (e.g., MQC) or detectability (e.g., MDC) established for the project (see Sections 3.8 and 5.5). Historical data that do not meet the objectives of the disposition survey may still be used to provide estimates for radionuclide concentrations or levels of radioactivity.

The results of the IA may provide estimated radionuclide concentrations or levels of radioactivity based on process knowledge, historical data, sentinel measurements, or preliminary surveys. In some cases, a survey is performed to develop adequate estimates for levels and variability of radionuclide concentrations or radioactivity. Again, the planning team should evaluate the data used to develop the estimated radionuclide concentrations or levels of radioactivity. In general, estimated data will have a higher associated uncertainty than known data that meet the objectives of the project. The planning team should keep this in mind when

developing estimates for radionuclide concentrations or radioactivity to be used in classifying M&E.

If the action level is defined in terms of average activity, the average radionuclide concentration or radioactivity should be compared to the action level to determine the appropriate classification. Similar comparisons should be developed for action levels provided in terms of maximum activity or total activity. For example, DOE Order 5400.5 (DOE 1993) provides three surface activity action levels for each group of radionuclides: average total surface activity, maximum total surface activity, and maximum removable surface activity. These action levels must be evaluated prior to disposition of the M&E. Classification would be determined by comparing the average total surface activity, maximum total surface activity, and maximum removable surface activity (or appropriate conservative estimates) to the corresponding action level. The overall classification would be determined by the most restrictive case. If the maximum total surface activity indicates the M&E is Class 1, while the maximum removable surface activity indicates the M&E is Class 3, the M&E should be classified as Class 1.

The improper classification of M&E has serious implications, particularly when it leads to the release of material with residual radioactivity in excess of the AL. For example, if material were mistakenly thought to have a very low potential for having residual radioactivity, the material will be subjected to a survey with lesser scrutiny. This misclassification might result in releasing material that should not be released. The opposing possibility (i.e., when M&E is misclassified as impacted when it is non-impacted) involves the stakeholders expending potentially substantial resources involved in unnecessarily surveying non-impacted M&E.

4.4 Design the Disposition Survey

MARSAME recommends design of disposition surveys that measure 100% of the M&E being investigated whenever practical. This includes survey designs where all of the M&E are physically measured. Survey designs where physical measurements are performed for less than 100% of the M&E may be acceptable if the radioactivity is measurable. Measurable radioactivity is radioactivity that can be quantified and meets the DQOs and MQOs established for the survey. Radioactivity that is quantified using known or predicted relationships developed from process knowledge, historical data, sentinel measurements, or preliminary measurements is considered measurable as long as the relationships are developed and verified as specified in the DQOs and MQOs. An example of such a relationship could be the immobile progeny of the measured radionuclides.

Survey designs that measure 100% of the M&E being investigated reduce the uncertainty in the final decision. Because 100% of the M&E are measured, for practical purposes spatial variability can be ignored. Attention should be given to ensure that all impacted surfaces are measured in 100% scan surveys. Surveys that use known or predicted relationships to estimate radionuclide concentrations or levels of radioactivity need to account for the contribution of spatial variability to total uncertainty.

To make the best use of limited resources, MARSAME places the greatest level of survey effort on M&E that have, or had, the greatest potential for residual radioactivity (i.e., Class 1). This is

referred to as a graded approach. As noted in Section 1.3, survey designs that measure 100% of the M&E are often neither practical nor cost-effective, and could drive the user to dispose of any material that is potentially impacted without considering the benefits of reuse or recycle. The use of a graded approach to ensure that a sensible, commensurate balance is achieved between cost and risk reduction should always be incorporated into MARSAME survey designs. The following sections describe the four basic disposition-survey designs:

- Scan-only survey designs (Section 4.4.1),
- In situ survey designs (Section 4.4.2),
- Survey designs that combine scans and static measurements (MARSSIM-type surveys, Section 4.4.3), and
- Method-based survey designs (Section 4.4.4).

Figures 4.5, 4.6, and 4.7 illustrate the process of designing a disposition survey. Classification can be used to provide a graded survey approach to individual survey designs. Information on adjusting the level of survey effort based on classification is provided for each type of survey design. Each survey design can include a variety of survey techniques (Section 5.9).

4.4.1 Scan-Only Survey Designs

Scan-only survey designs use scanning techniques to measure the M&E. The detector is moving at a constant speed relative to the M&E being surveyed while maintaining a constant distance relative to the M&E. In general, scan-only survey designs may be applied to all types of M&E, from small individual items to large quantities of materials to large, complex machines. Scan techniques include hand-held instruments that are moved over the M&E, as well as systems that move the M&E past stationary detectors (e.g., conveyor systems). For example, a scan-only survey may involve the use of a Geiger-Mueller (GM) pancake detector to measure potential surface radioactivity on hand tools. Alternatively, a scan-only survey could involve the use of a conveyORIZED system that measures large quantities of M&E (e.g., bulk material or laundry). Scan-only surveys generally are applicable to all types of disposition surveys.

Scan-only survey designs often require the least amount of resources to design and implement, and are easy to incorporate into SOPs or project-specific survey designs. In many cases it is not necessary to document the results of individual scanning measurements because it is easy to identify results that exceed some threshold corresponding to the action level. With the real-time feedback available during Class 1 scan-only surveys, the user can implement a “clean as you go” practice by segregating M&E that exceed the threshold for additional investigation. Drawbacks to scan-only surveys include increased measurement uncertainty because of variations in scan speed and source to detector distance making it difficult to detect or quantify radionuclides with action levels close to zero or background.

Scan-only surveys are characterized by large numbers of measurements with relatively short count times. Measurement uncertainty should account for variations in source-to-detector distance, scan speed, and surface efficiency that are commonly associated with scanning measurements.

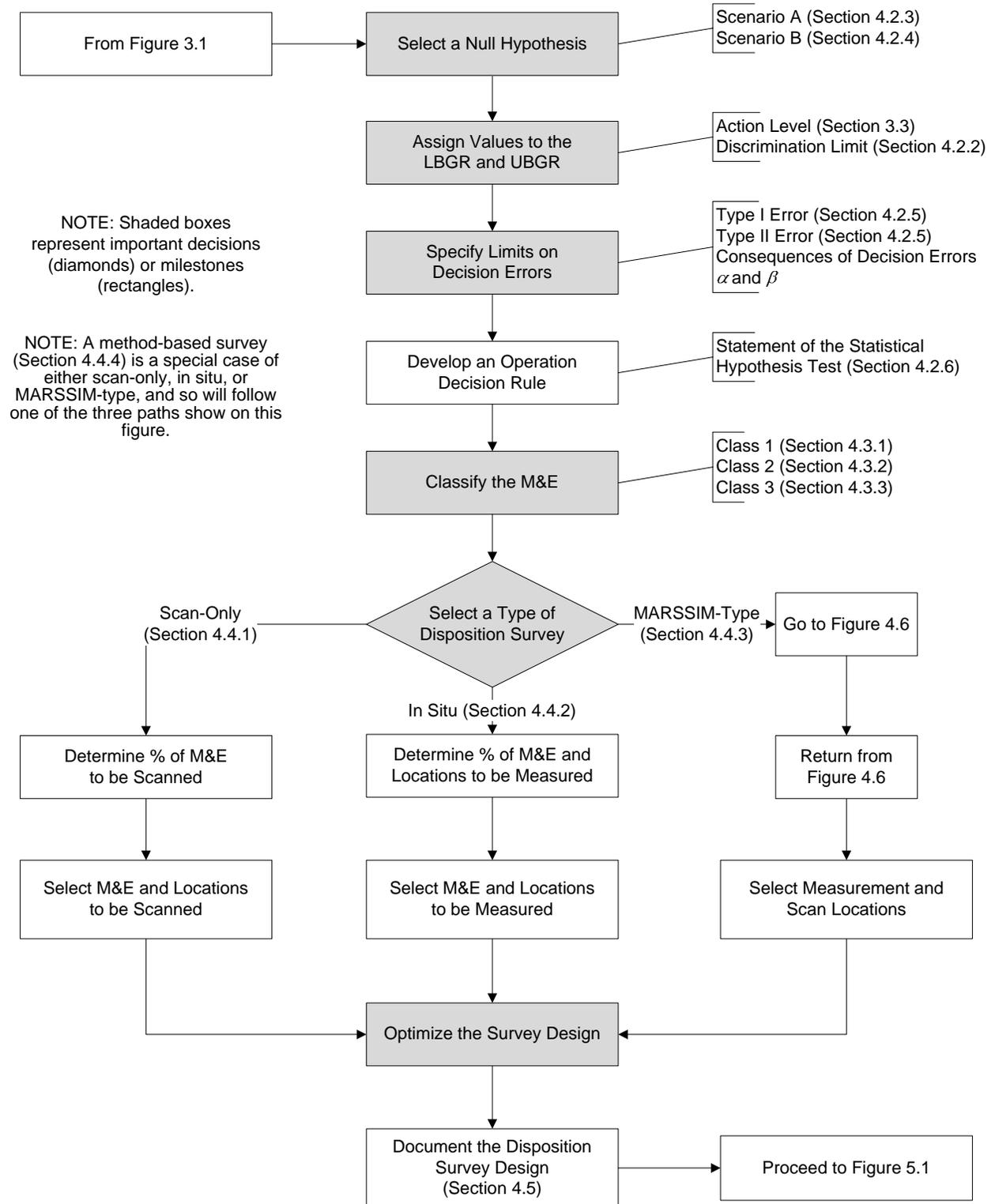


Figure 4.5 Flow Diagram for a Disposition Survey Design

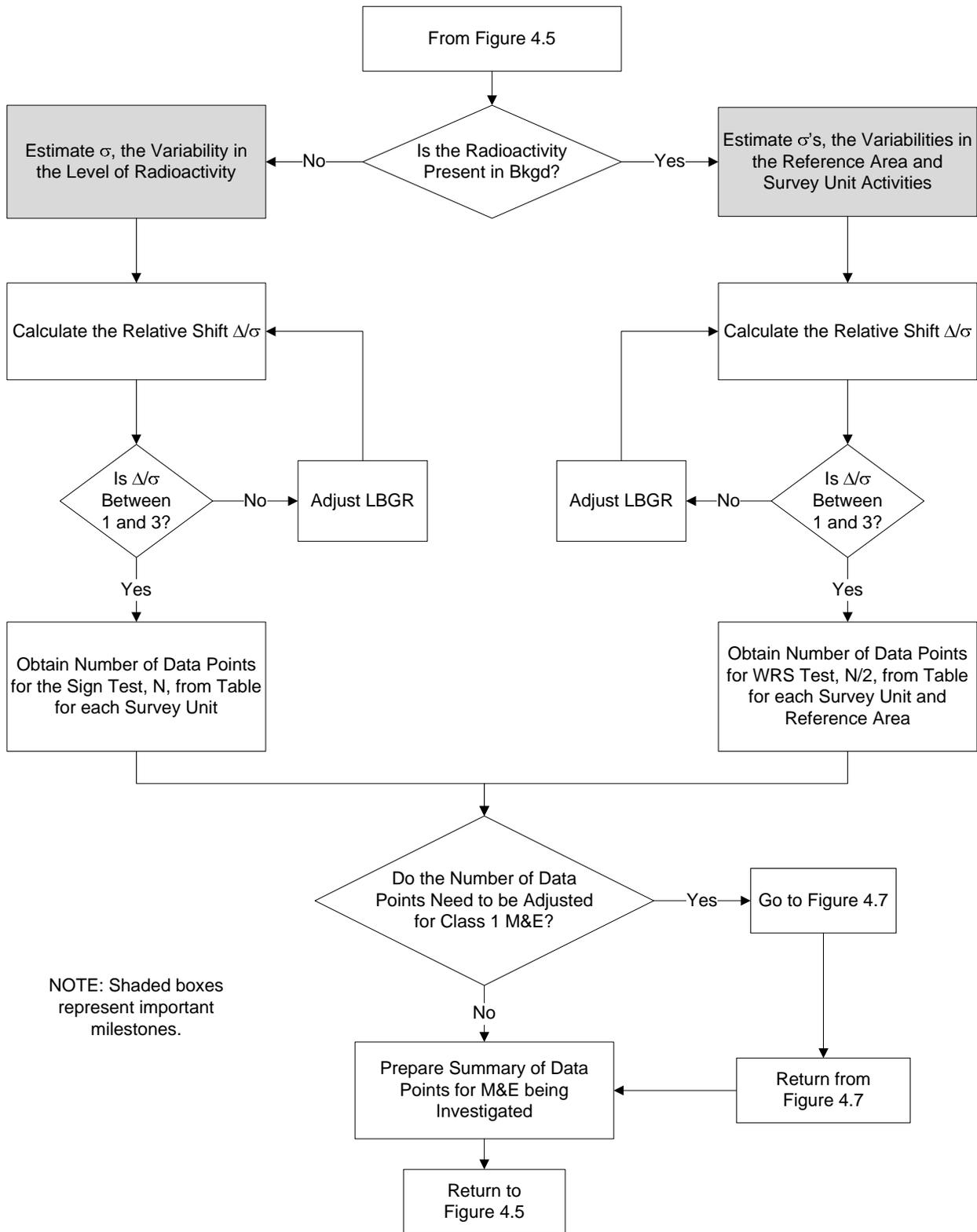


Figure 4.6 Flow Diagram for Identifying the Number of Data Points for a MARSSIM-Type Disposition Survey

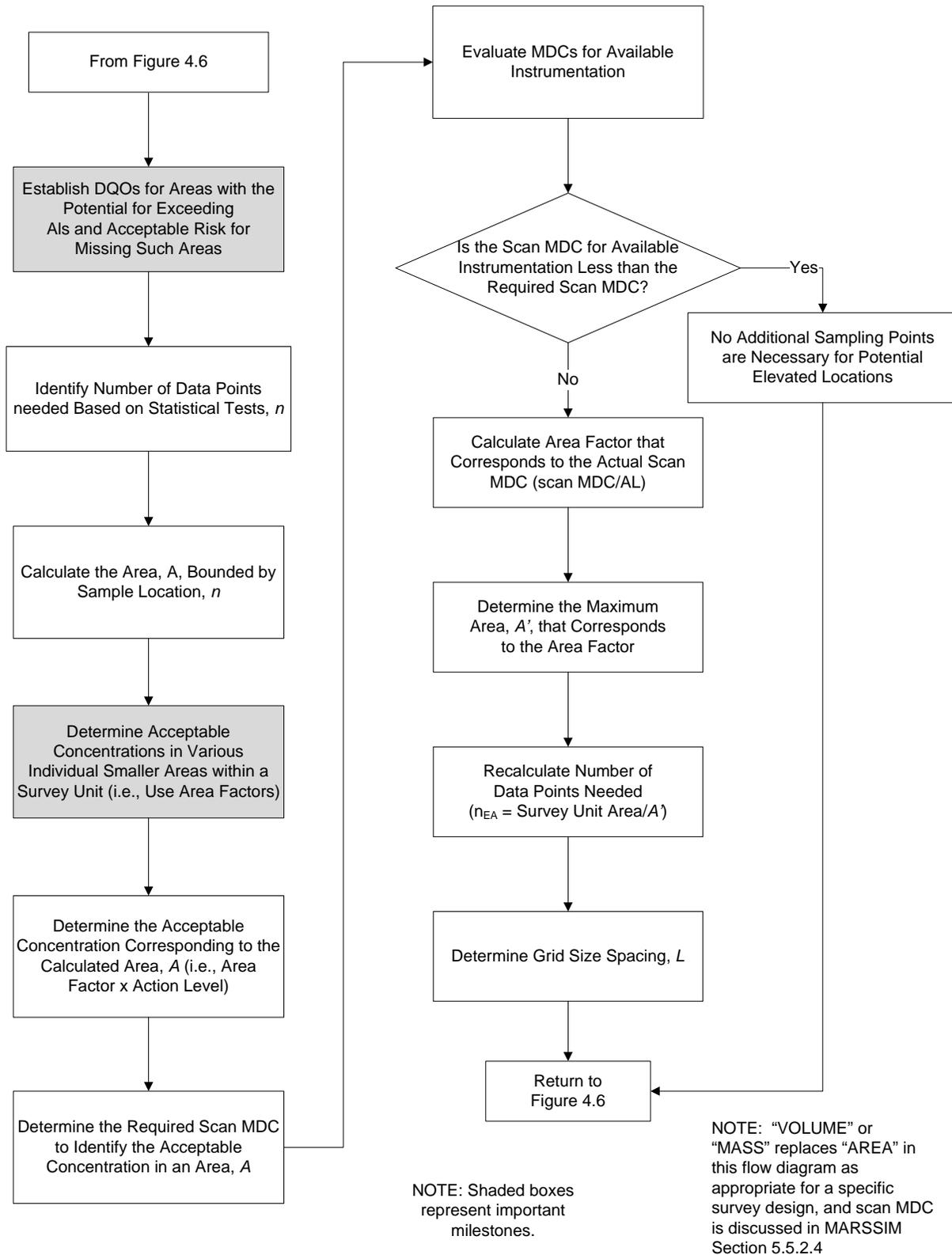


Figure 4.7 Flow Diagram for Identifying Data Needs for Assessment of Potential Areas of Elevated Activity in Class 1 Survey Units for MARSSIM-Type Disposition Surveys

Evaluation of scan-only survey data depends on whether or not individual measurement results are recorded (Section 6.2.5). The decision of whether to record individual measurement results will impact the selection of instrumentation (Section 5.9) and survey documentation requirements (see Sections 4.5, 5.11, and 6.9), and may impact handling of the M&E (Section 5.3).

4.4.1.1 Class 1 Scan-Only Surveys

Class 1 scan-only surveys require that physical measurements be performed for 100% of the M&E being investigated. For individual items this may require scanning both sides of flat items (e.g., sheet metal, boards) and changing the surveyor's grip on the item to ensure all areas are surveyed (e.g., handles). For conveyor systems this may require flipping or rotating the M&E and performing additional measurements. Conveyor systems can also be designed with detectors surrounding the M&E (e.g., above and below a conveyor belt) to provide 100% measurability.

4.4.1.2 Class 2 Scan-Only Surveys

Class 2 scan-only surveys use information about the M&E to reduce the total area surveyed using a graded approach. The amount of the M&E surveyed is calculated based on the relative shift (i.e., Δ/σ). The percent of the M&E to be surveyed is 10%, or the result using Equation 4-1, whichever is larger:

$$\% \text{ Scan} = \frac{\left(10 - \frac{\Delta}{\sigma}\right)}{10} \times 100\% \quad (4-1)$$

The amount of M&E to be scanned should be rounded up to the next 10 percent, and at least 10% of the M&E must be surveyed. For example, if the percent scan is 51%, then 60% of the M&E will be surveyed. This means that between 10 to 100% of Class 2 M&E would be measured during the disposition survey. Figure 4.8 shows the relationship between the relative shift and the amount of M&E to be scanned.

The scanned percentages need to represent spatially uniform coverage of the survey unit and coincide with the conceptual model for the M&E. Consider spatially uniform coverage when scanning 30% of a desk and 30% of a bucket of bolts. For the desk example, 30% coverage during scanning may be derived from performing scans on the top surface, the legs, inside the drawers, etc., so that essentially 30%

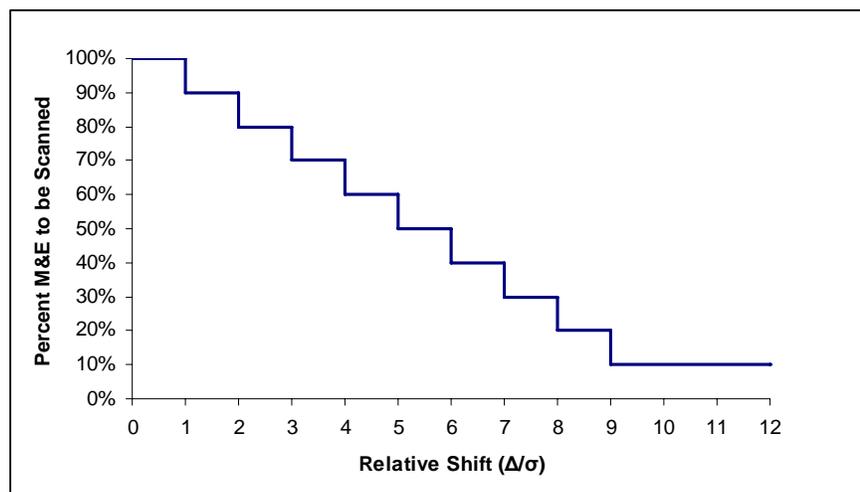


Figure 4.8 Relationship Between the Relative Shift and the Amount of M&E to be Scanned

of each surface is scanned, yielding 30% total coverage of the entire desk. For the bucket of bolts example, 30% scanning coverage means laying out all the bolts and scanning 30% of them as well as 30% of the bucket itself. Alternatively, if the conceptual model for the desk showed a higher potential for contamination on the top, bottoms of legs, and drawer handles, 100% of these areas could be scanned with smaller amounts of the areas with a lower potential for radioactivity scanned to provide a total of 30% coverage for the entire desk. The graded approach should be applied to all aspects of the survey design.

The selection of M&E to survey as part of a Class 2 survey is project specific and is determined based on what is known about the M&E. For example, if all of the M&E is accessible and is expected to have uniform radionuclide concentrations or levels of radioactivity, the M&E to be surveyed should be selected randomly. However, there may be areas that are difficult-to-access with the instrumentation selected to perform the survey. If there is a known and accepted relationship between radionuclides in difficult-to-access areas and radionuclides in accessible areas, the Class 2 measurements may be biased to only accessible areas (i.e., representative of measurements in difficult-to-access areas).

If elevated radionuclide concentrations or levels of radioactivity are restricted to areas that can be readily identified (e.g., discolored areas, corners, cracks, access points) the Class 2 measurements may be designed to concentrate on these biased areas. The Class 2 survey design should include a combination of biased and random areas to check assumptions used to support the survey design.

The selection of M&E to survey may also depend on the physical characteristics of the M&E. For example, surveying 40% of the inside of a railroad car would be different from surveying 40% of a pile of rubblized concrete. Section 5.3 provides information on handling M&E and determining what will be measured during implementation of the survey design.

4.4.1.3 Class 3 Scan-Only Surveys

Class 3 scan-only survey designs are identical to Class 2 scan-only survey designs. The planning team may decide that some Class 3 scan-only disposition surveys require that less than 10% of the M&E will be measured. The decision to design a survey requiring less than 10% of the M&E to be measured should be based on the total uncertainty associated with the disposition decision. The determination of total uncertainty should be based on process knowledge, historical data, and the results of preliminary and disposition surveys.

In addition, some Class 3 scan-only survey designs may be based solely on biased measurements. In other words, random measurement locations are not required for Class 3 scan-only survey designs. However, if biased measurements are reasonable, they should be performed, keeping in mind that Class 3 M&E have very little or no potential for exceeding the AL.

4.4.2 In Situ Survey Designs

In situ survey designs use static measurements to measure 100% of an item. The detector and the item being measured are held in a fixed geometry⁵ for a specified count time to meet the MQOs. There are a wide variety of in situ measurement techniques available. Examples include box counters, portal monitors, and in situ gamma spectrometry systems, as well as direct measurements with hand-held instruments (e.g., NaI(Tl), ZnS, GM pancake, and portable gas proportional detectors). In situ surveys generally are applied to situations where scan-only surveys are determined to be unacceptable. For example, variations in source-to-detector distance, scan speed, and surface efficiency that are commonly associated with scanning measurements can often be effectively controlled using an in situ survey design.

In situ surveys are characterized by limited numbers of measurements with long count times (relative to scan-only surveys). Measurement uncertainty will incorporate spatial uncertainty because of the source geometry assumed in the calibration. Thus, special attention needs to be made to the assumptions made in the calibration of in situ systems. Potential deviations from these assumptions need to be propagated through the calibration equation to assess the total measurement uncertainty (see Sections 5.6 and 7.4). Count times are determined by the MQOs rather than the time constant of the measurement system. In situ measurements provide a 100% measurement for some portion of the M&E being investigated. The M&E may be an individual item or piece of equipment, or some fraction of a large quantity of material determined by the solid angle coverage of the detector.

In situ surveys may consist of a single measurement, or a series of measurements. Single measurement surveys typically are performed on individual items or relatively small batches of M&E. A series of in situ measurements may be used to evaluate larger quantities of M&E. In some cases, a series of in situ measurements may be performed of a single item or batch of M&E to provide several estimates of the radionuclide concentrations from different angles. The primary difference between an in situ survey and a MARSSIM-type survey is that an in situ survey measures 100% of an item (using one or several measurements) to determine the average radionuclide concentration for that item. A MARSSIM-type survey uses a statistically based number of measurements (that generally do not measure 100% of the item or group of items being surveyed) to calculate an average radionuclide concentration for that item or group of items.

4.4.2.1 Class 1 In situ Surveys

Class 1 in situ surveys require that physical measurements be performed for 100% of the M&E being investigated. Placing an item inside a 4- π measurement system, performing a series of measurements with overlapping fields of view that incorporate all of the M&E, or rotating the M&E within the field of view of the detector so 100% of the M&E are measured are examples where 100% of the M&E are measured.

⁵ There are situations where the levels of radioactivity for M&E being measured are expected to be inhomogeneous. Certain measurement systems can rotate the M&E during a measurement to provide an estimate of the average activity. For the purposes of this section, these are considered fixed geometries. Additional discussion on the limitations of these systems is provided in Chapter 5.

4.4.2.2 Class 2 In situ Surveys

Class 2 in situ surveys use information about the M&E to reduce the total area surveyed using a graded approach. The amount of the M&E surveyed is calculated based on the relative shift (i.e., Δ/σ). The percent of the M&E to be surveyed is 10% or the result using Equation 4-2, whichever is larger:

$$\% \text{ Measured or } \% \text{ Solid Angle Coverage} = \frac{\left(10 - \frac{\Delta}{\sigma}\right)}{10} \times 100\% \quad (4-2)$$

The fraction of the M&E or the solid angle coverage of the M&E to be surveyed should be rounded up to the next 10 percent. If the % coverage is 51%, then 60% of the M&E will be surveyed. This means that 10 to 100% of Class 2 M&E would be measured during the disposition survey. Figure 4.8, on page 4-13, shows the relationship between the relative shift and the amount of M&E to be surveyed.

The selection of M&E to survey as part of a Class 2 survey is project specific and is determined based on what is known about the M&E. For example, if all of the M&E is accessible and is expected to have uniform radionuclide concentrations or levels of radioactivity, the M&E to be surveyed should be selected randomly. However, there may be areas that are difficult-to-access with the instrumentation selected to perform the survey. If there is a known and accepted relationship between radionuclides in difficult-to-access areas and radionuclides in accessible areas, the Class 2 measurements may be biased to only accessible areas (i.e., representative of measurements in difficult-to-access areas). If elevated radionuclide concentrations or levels of radioactivity are restricted to areas that can be readily identified (e.g., discolored areas, corners, cracks, access points) the Class 2 measurements may be designed to concentrate on these biased areas. The Class 2 survey design should include a combination of biased and random areas to check assumptions used to support the survey design.

4.4.2.3 Class 3 In situ Surveys

Class 3 in situ survey designs are identical to Class 2 in situ survey designs. The planning team may decide that some Class 3 in situ disposition surveys require that less than 10% of the M&E will be measured. The decision to design a survey requiring less than 10% of the M&E to be measured should be based on the total uncertainty associated with the decision based on process knowledge, historical data, and the results of preliminary and disposition surveys.

4.4.3 MARSSIM-Type Survey Designs

MARSSIM-type survey designs combine a statistically based number of static measurements to determine average radionuclide concentrations or radioactivity levels with scanning to identify areas of elevated radionuclide concentrations or radioactivity for specified quantities of M&E (i.e., survey units). Identifying survey unit sizes, laying out systematic measurement grids, and calculating project- and item-specific area factors requires a significant effort. Section 5.3 discusses considerations for handling M&E, including locating measurements. The planning team should consider that MARSSIM-type survey designs might be more complex and require

more resources than scan-only or in situ survey designs that meet the DQOs. Information on designing MARSSIM-type surveys is found in MARSSIM Section 5.5. In general, MARSSIM-type surveys of M&E are only performed on large, complicated M&E with a high inherent value after scan-only and in-situ surveys have been considered and rejected.

4.4.3.1 Class 1 MARSSIM-Type Surveys

Class 1 MARSSIM-type surveys calculate the required number of measurements in each survey unit based on the shift (i.e., Δ), the variability in the radionuclide concentrations or levels of radioactivity (i.e., σ), and the Type I and Type II decision error rates (i.e., α and β). The number of measurements per survey unit is adjusted to account for small areas of elevated activity using the information in MARSSIM Section 5.5.2.4. In addition, scan measurements are required for 100% of the M&E being investigated.

The development of survey unit boundaries is discussed in Section 3.6. The quantity of M&E in each survey unit should be determined based on the modeling assumptions used to develop the action levels.

The variability in the radionuclide concentrations in each survey unit can be estimated using the standard deviation of preliminary measurements or the uncertainties from individual measurements, whichever is larger. Whenever practical, preliminary data should be used to provide estimates of variability. As a last resort when preliminary data are not available, MARSSIM states that assuming a coefficient of variation on the order of 30% may be reasonable (MARSSIM Section 5.5.2.2, Page 5-26). This 30% is used as a starting point for the DQO process, and should be adjusted iteratively during the development of a final survey design. For M&E, MARSAME recommends using a higher percentage value.

Area factors are specified in a regulation or other guidance, or developed based on the changes in dose or risk associated with changing the area (or volume) of activity to be less than the entire survey unit. For example, DOE Order 5400.5, Figure IV-1 (DOE 1993) allows use of an area factor of up to 3.0 for total surficial radioactivity for all radionuclides, NUREG-1640 (NRC 2003a) is only concerned with average activity and total inventory of radioactivity, which implies that within the survey unit relatively high localized concentrations of radioactivity could exist. This implication does not mean that a large part of the survey unit may be used to intentionally “dilute” high concentrations of radioactivity. Rather, in the course of normal processing there is a non-prescriptive flexibility allowed for inhomogeneity of radionuclide concentrations. Nevertheless, mixing different classes of M&E (Class 1, 2, and 3) is not allowed. The physical characteristics of the M&E combined with potential future exposures based on the selected disposition option mean that area factors (and possibly exposure pathway dose or risk models) need to be developed for each project. In the absence of regulation-specific area factors, assuming an area factor of 1.0 for all radionuclides would be the most conservative approach. Depending on the basis of the action level, an area factor may or may not be applicable. MARSSIM uses completely different scenarios for real property to develop area factors in contrast to those scenarios used for M&E in NUREG-1640 (NRC 2003a). Area factors may be derived on a project-specific basis using project-specific scenarios.

If the radioactivity being measured is present in background, Table 5.3 in MARSSIM provides the number of measurements required in each survey unit as well as in each reference area. MARSSIM Section 5.5.2.2 and NUREG-1505 (NRC 1998a) Sections 9.4 and 9.5 provide information on calculating the number of required measurements when the radioactivity being measured is present in background.

If the radioactivity being measured is not present in background, Table 5.5 in MARSSIM provides the number of measurements required in each survey unit. MARSSIM Section 5.5.2.3 and NUREG-1505 (NRC 1998a) Sections 9.2 and 9.3 provide information on calculating the number of required measurements when the radioactivity being measured is not present in background. For convenience, statistical sample size and critical value tables for the Sign and Wilcoxon Rank Sum (WRS) tests taken from MARSSIM Appendix I are given in MARSAME Appendix A. In addition, Appendix A contains a table of critical values for the Quantile test, taken from NUREG-1505.

Whenever area factors other than 1.0 are used to design the disposition survey, a systematic grid should be used to determine measurement locations. The systematic grid determines the largest area that could be missed by the measurements which is used to determine the required scan MDC. Section 5.3 provides information on handling M&E, including setting up systematic grids.

4.4.3.2 Class 2 MARSSIM-Type Surveys

Class 2 MARSSIM-type surveys are similar to Class 1 MARSSIM-type surveys. The numbers of measurements in each survey unit are determined in the same manner, although the expected radionuclide concentrations or levels of radioactivity and the decision error rates may change. Unlike MARSSIM, the survey unit size remains the same and does not change based on classification. The portion of the survey unit where scan surveys are required is reduced to between 10 and 100%. The information in Section 4.4.1.2 for Class 2 scan-only surveys should be used to determine the areas to be scanned. This recommendation is provided for M&E only, and is not intended to update the guidance in MARSSIM for surface soils and building surfaces.

4.4.3.3 Class 3 MARSSIM-Type Surveys

Class 3 MARSSIM-type surveys are similar to Class 1 MARSSIM-type surveys. The numbers of measurements in each survey unit are determined the same way, although the expected radionuclide concentrations or levels of radioactivity and the decision error rates may change. Unlike MARSSIM, the survey unit size does not change based on classification. The portion of the survey unit where scan surveys are required is reduced to less than 10% and is based on professional judgment. The information in Section 4.4.1 for scan-only surveys should be used to determine the areas to be scanned. This recommendation is provided for M&E only, and is not intended to update the guidance in MARSSIM for surface soils and building surfaces.

4.4.4 Method-Based Survey Designs

The action level selected in Section 3.3 may implicitly or explicitly require using a specific measurement technique (Section 5.9.1) or instrument (Section 5.9.2). A survey design that is

based on a required measurement method, or combination of measurement technique and instrumentation, is called a “method-based” survey design.

A method-based survey design is a scan-only, in situ, or MARSSIM-type survey design that incorporates the required measurement method. The survey design will still need to address all of the required components, such as number, type, location, and sensitivity of measurements. Survey components that are not specified as part of the required measurement method should be identified and addressed using the DQO process.

4.4.5 Optimize the Disposition Survey Design

The disposition survey design process described in this supplement could result in the development of multiple potential disposition survey designs. For example, consider the case when simultaneous compliance with more than one action level is required (e.g., DOE 1993). In other cases the decision resulting from one survey may lead to the requirement of another survey, such as failure to demonstrate compliance with the disposition criterion for release resulting in a survey to comply with radioactive waste acceptance criteria. Multiple survey designs could result from selection of multiple potential disposition options, action levels, survey techniques, measurement systems, decision rules, or some combination of these factors. Before the planning team can proceed, all of the potential disposition survey designs need to be reviewed to select a final disposition survey design.

The final step in the DQO process (“Develop the Detailed Plan for Obtaining Data,” Step 7) is designed to produce the most resource-efficient survey design that is expected to meet the DQOs. It may be necessary to revisit previous steps in the DQO process and work through this step more than once.

There are five activities included in this step:

1. Review existing data (e.g., historical data, sentinel measurement results, preliminary survey results). Use existing data to support the data collection design. If no existing data are available, consider performing preliminary surveys to acquire estimates of variability to determine numbers of measurements. Evaluate potential problems regarding detection limits or interferences. If new data will be combined with existing data, determine if there are data gaps that need to be filled or deficiencies that can be mitigated prior to implementing the disposition survey design.
2. Evaluate operational decision rules. The theoretical decision rules developed in Section 3.6 were based on the assumption that the true radionuclide concentrations or radioactivity present in the M&E were known. Operational decision rules based on the statistical tests (Chapter 6) should replace the theoretical decision rule (see Sections 3.5 and 4.2.6). Review the parameter of interest (e.g., maximum measured value, mean or median radionuclide concentration) and the possible statistical tests that could be applied to the data to evaluate the operational decision rules.
3. Develop general data collection design alternatives. Sections 4.4.1, 4.4.2, and 4.4.3 provide information on general data collection design alternatives applicable to disposition surveys.

Consider individual instruments and measurements techniques (Section 5.9) combined with general data collection designs to develop alternative survey approaches.

4. Calculate the number of measurements or amount of M&E to be surveyed. Sections 4.4.1, 4.4.2, and 4.4.3 provide general information on determining the level of survey effort for the general data collection design alternatives based on classification. Determine the estimated resources required for each of the alternative survey approaches.
5. Select the most resource-effective survey design. Evaluate each of the survey approaches based on the required resources and the ability to meet the DQO and MQO constraints within the tolerable decision error limits. The survey design that provides the best balance between cost and meeting survey objectives while considering the non-technical economic and health factors imposed on the project is usually the most resource-effective. The statistical concept of a power curve (MARSSIM Appendix I.9) is extremely useful in investigating the performance of alternative survey designs.

If none of the alternative survey designs meet the survey objectives within the tolerable decision error limits while considering the budget or other constraints, then the planning team will need to relax one or more of the constraints. Examples include—

- Increasing the budget for implementing the survey;
- Using exposure pathway modeling to develop site-specific action levels;
- Increasing the decision error rates, not forgetting to consider the consequences associated with making an incorrect decision;
- Increasing the width of the gray region for Scenario A surveys by decreasing the average activity associated with the M&E which may require remediation, or negotiating a higher UBGR for Scenario B which may require additional reference area investigations;
- Relaxing other project constraints (e.g., schedule);
- Changing the boundaries—it may be possible to reduce measurement costs by changing or eliminating survey units that will require different decisions;
- Segregating the M&E based on physical or radiological attributes (Section 5.4);
- Evaluating alternative measurement techniques with lower detection limits or lower survey costs;
- Adjusting the list of radionuclides or radiations of concern (Section 3.2); and
- Considering other disposition options that will result in higher action levels.

4.5 Document the Disposition Survey Design

Documentation of the disposition survey design should provide a complete record of the selected survey design. The documentation should include all assumptions used to develop the survey design, a detailed description of the M&E being investigated, along with the DQOs and MQOs for the survey (e.g., MQC, MDC, count time). The regulatory basis for the disposition criterion and calculations showing the derivation of action levels should also be provided. Sufficient data and information should be provided to enable an independent re-creation and evaluation of the disposition survey design. The documentation should provide information on the following topics:

- Information on *who* developed, reviewed, and approved the survey design, as well as training and qualification requirements for such individuals, should be included, along with any requirements for who can implement the survey design.
- Information on *what* M&E were considered when developing the survey design along with a description of M&E to which the survey design applies.
- Information on *when* the survey design was developed along with when the survey design will be implemented including restrictions on time of day, time of year, and count times when applicable.
- Information on *where* the survey design can be applied (including restrictions on local background levels) along with measurement locations including fraction of M&E to be surveyed and locations of direct measurements or samples or methods for selecting locations during implementation,
- Information on *why* a survey should be performed including justification for impacted and non-impacted decisions and assignment of classifications,
- Information on *how* the survey will be performed including measurement techniques and instruments along with instructions for segregating and handling the M&E during the survey.

There are two methods for documenting surveys described in the following sections, based on the type of project—

- Routine or repetitive surveys, and
- Case-specific applications.

4.5.1 Routine Surveys and Standard Operating Procedures

Routine (or repetitive) surveys are disposition surveys that are routinely performed on M&E entering or leaving an operating facility. Examples of routine surveys include—

- Clearance of tools from radiological control areas at a radiation facility,
- Preparation of low-level radioactive waste for disposal, and
- Interdiction of scrap metal entering a recycling facility.

Documenting routine survey designs, for example as SOPs, can be consistent with MARSAME recommendations. SOPs detail the work processes that are conducted or followed within an organization and document the way activities are performed. SOPs that also meet the DQOs for the disposition survey can be used to document routine survey designs. The development and use of SOPs facilitates consistent conformance to technical and quality system requirements. They promote quality through consistent implementation of a process within an organization, even if there are temporary or permanent personnel changes. The benefits of a valid SOP are reduced work effort combined with improved data comparability, credibility, and legal defensibility (EPA 2001). Additional guidance on developing SOPs, including example SOPs, is provided in EPA QA/G-6 (EPA 2001).

4.5.1.1 SOP Process

The organization developing the SOP should have a procedure in place for determining what procedures or processes need to be documented. SOPs documenting these procedures or processes should be written by individuals knowledgeable with the activity and the organization's internal structure. For disposition survey designs, a team approach to writing SOPs is often used. This allows input from subject-matter experts with information critical to the survey process, and promotes acceptance of the SOP once it is completed.

SOPs should be concise and provide step-by-step instructions in an easy-to-read format. They should provide sufficient detail so that a technician with limited experience, but with a basic understanding of the process, can successfully implement the survey design when unsupervised. Disposition survey SOPs should be reviewed and validated by one or more individuals with appropriate training and experience in performing surveys of M&E before they are implemented. It may be helpful to have the draft SOP field tested by someone not directly involved in the development of the SOP. The review process for disposition surveys should include a regulatory review and appropriate stakeholder involvement.

SOPs need to remain current. SOPs should be updated and re-approved whenever survey procedures are changed. SOPs should be systematically reviewed on a periodic basis to ensure that the policies and procedures remain current and appropriate.

Many disposition survey activities use checklists or forms to document completed tasks (e.g., daily instrument checks). Any checklists or forms included as part of the disposition survey should be referenced at the points in the procedure where they are used and attached to the SOP. Remember that the checklist or form is not the SOP, but a part of the SOP.

The organization should have a system for developing, reviewing, approving, controlling, and tracking documents. This process is usually documented in the Quality Management Plan.

4.5.1.2 General Format for Disposition Survey SOPs

In general, disposition survey SOPs consist of five elements:

- Title Page,
- Table of Contents,
- Procedures,
- Quality Assurance and Quality Control, and
- References.

The title page should include a title that clearly identifies the activity, an identification number, date of issue or revision, and the name of the organization to which the SOP applies. The signatures and signature dates of individuals who prepared and approved the SOP also should be included.

The table of contents lists the major section headings and the pages where the information is located. This provides a quick reference for locating the desired information and identifies changes or revisions made to individual sections.

The procedures are specific to the disposition survey design and may include some or all of the following topics:

- Scope and applicability. This section should provide a detailed description of the M&E to which the SOP can be applied. In addition, it is often important to clearly identify M&E to which the SOP does not apply.
- Summary of method. This section briefly describes the overall survey design, identifies the disposition option, lists the action levels, and provides their regulatory basis. The details on the development of the action levels based on the disposition criterion in the regulations is generally referenced or included as an attachment.
- Definitions. This section identifies and defines any acronyms, abbreviations, or specialized terms used in the SOP.
- Health and safety warnings. This section indicates operations that could result in personal injury, loss of life, or uncontrolled release to the environment. Explanations of what could happen if the procedure is not followed or if it is followed incorrectly should appear here as well as the critical steps in the procedure.
- Cautions. This section identifies activities that could result in equipment damage, degradation of data, or possible invalidation of results. Explanations of what could happen if the procedure is not followed or if it is followed incorrectly should appear here as well as the critical steps in the procedure.
- Interferences. This section describes any component of the process that may interfere with the final decision regarding disposition of the M&E.
- Personnel qualifications. This section lists the minimum experience required for individuals implementing the SOP. Any required certifications or training courses should be listed. For many routine surveys the training records of the personnel implementing the survey design are used to document compliance with the SOP.
- Equipment and supplies. This section lists and specifies the equipment, materials, reagents, and standards required to implement the SOP. At a minimum, this section must identify the model number and manufacturer of instruments that will be used to perform the survey.
- Roles and responsibilities of project personnel. This section identifies the decision-maker for the project as well as identifying who is responsible for performing specific tasks. An organizational chart documenting the chain of command and reporting authority (including quality control, health and safety, and any subcontractors) is a useful tool for showing potential interactions between project team members.
- Procedure. This section provides all pertinent steps, in order, and materials needed to implement the survey design. This section should include—
 - Instrument or method calibration and standardization (generally requires a check of the instrument calibration date and lists the appropriate MQOs such as MQC or MDC and references the details for these processes),
 - Type, number, and location of measurements,
 - Data acquisition, calculations, and data reduction requirements,
 - Troubleshooting, and

- Computer hardware and software.
- Data and records management. This section describes the forms to fill out, reports to be written, and data and record storage information. At a minimum routine survey records should identify the personnel performing measurements and the instruments used to perform the measurements (i.e., model and serial number for all components of the measurement system). These records should show that the personnel performing the survey were properly trained and the instruments used to collect the data were calibrated and operating properly. This section should clearly state whether individual measurement results will be recorded, because this information is not always required.

The QA/QC section describes the activities required to demonstrate the successful performance of the disposition survey. For many organizations the QC activities for individual instruments are provided in separate SOPs describing the proper use of that instrument, so the daily checks of the instruments are included by reference. The QA/QC section should identify QC requirements for the disposition survey such as blanks, replicates, splits, spikes, and performance evaluation checks. The frequency for each QC measurement should be listed along with a discussion of the rationale for decisions. Specific criteria should be provided for evaluating each type of QC measurement, as well as actions required when the results exceed the QC limits. The procedures for reporting and documenting the results of QC measurements should be listed in the QA/QC section. Section 5.10 provides additional information on QC for disposition surveys.

The reference section should list all documents or SOPs that interface with the routine survey SOP. Full references (including SOP versions and dates) should be provided. Published literature and instrument manuals that are not readily available should be attached.

4.5.2 Case-Specific Applications

There are M&E that may require a disposition survey that are not covered by routine surveys. These are collectively referred to as case-specific applications. Case-specific applications include project-specific applications such as decommissioning or cleanup surveys, as well as unique applications involving one-time disposition of special equipment from a facility.

Ideally, documentation of case-specific survey designs involves a comparable level of effort associated with routine surveys. This is obviously the case for large decommissioning or cleanup projects where survey designs are documented as SOPs using a process analogous to routine surveys. The major differences are seen in the requirements for approval and maintenance of SOPs, which generally are less for decommissioning or cleanup projects compared to operating facilities. Disposition survey designs that will be applied during decommissioning or cleanup activities typically are documented as part of the survey design. However, a survey design needs to provide all of the information supporting the development of the disposition survey design, where SOPs typically focus on one aspect of the survey design or implementation. Historical information, process knowledge, description of the M&E, and assumptions used in the disposition survey design need to be included and not referenced.

The assumptions used to develop survey designs for routine surveys cannot be applied to all M&E, so situations will arise where a disposition survey design needs to be developed for

special items or unique applications. These types of surveys are often associated with M&E that have a high inherent value (e.g., large quantities of valuable materials, unique or very expensive equipment) to offset the resources required to develop a unique disposition survey design. These special survey designs need to be inclusive, providing all of the information supporting the development of the disposition survey design. Detailed discussions should be provided for all parts of the survey design, including selection of a disposition option, selection and development of action levels, development of MQOs and selection of instruments, and QA/QC requirements for individual measurement systems as well as for the entire disposition survey.

For most applications the disposition survey design is expected to be documented as a stand-alone survey plan or as a series of SOPs. However, the planning team may determine that the survey design documentation can be combined with the results of the survey into a single document. At a minimum, instructions on the type, number, and location of measurements should be documented to provide instructions to the technicians performing the survey.

Documenting the entire disposition decision process in a single document is most appropriate for unique applications where there is sufficient historical information or survey precedent such that there is little uncertainty associated with the development of a survey design. The benefit of documenting all of the survey decisions (e.g., design, implementation, and assessment) in one document is the savings in resources to develop multiple documents. The risk associated with not documenting the survey design process until after implementation is that the assessment will identify some problems with the survey design requiring additional data collection which could impact project costs and schedule.